Table 11-1
Screening of Technologies for Unsaturated Waste and Soil

Technology	Description	Effectiveness	Implementability	Relative Cost	Retained?	Comments
In Situ Biological Treatment						
Bioventing	Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.	○	●	●	Yes	Potentially effective for treatment of the unsaturated waste and soils to reduce concentrations of the principal COCs that are found in groundwater at Sauget Area 1 (i.e., benzene, chlorobenzene, and 1,4-dichlorobenzene). Not effective for chlorinated ethenes, which require anaerobic conditions for most effective biodegradation. Not effective for SVOCs. (Note: Implementation of air sparging with SVE or biosparging of the saturated zone would result in some movement of air through the unsaturated zone soils and waste.)
Enhanced Bioremediation	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants or immobilization of inorganic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.	○	●	◎	—	Not effective where soil and waste contain NAPL.
Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment. Contaminants may be either organic or inorganic.	○	○	●	—	Not effective where soil and waste contain NAPL. Not effective for deep soils. Not all site COCs can be degraded by plants.
In Situ Physical/Chemical Treatment						
Chemical Oxidation	Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	◎	●	○	—	Expensive relative to other technologies at the scale required at Sauget Area 1.
Electrokinetic Separation	The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging. ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics. This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.	○	○	○	—	Not applicable to site conditions at Sauget Area 1.
Fracturing	Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies.	○	○	○	—	Not applicable to site conditions at Sauget Area 1.
Soil Flushing	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, which is then extracted and treated.	◎	●	○	—	Not effective for SVOCs. Expensive relative to other technologies at the scale required.

Notes:
COC = Chemical of concern. DNAPL = Dense non-aqueous phase liquid. GW = Groundwater. LNAPL = Light non-aqueous phase liquid. VOC = Volatile organic compound.

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Technology	Description	Effectiveness	Implementability	Relative Cost	Retained?	Comments
Soil Vapor Extraction	Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil through extraction wells. This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.	◉	●	●	Yes	Not effective for SVOCs and not effective for fill and waste materials below the water table. Can be used to capture vapors generated during air sparging or biosparging.
Solidification/Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	◉	●	◉	—	Not effective for VOCs.
In Situ Thermal Treatment						
Thermal Treatment	Steam/hot air injection or electrical resistance/electromagnetic/fiber optic/radio frequency heating is used to increase the volatilization rate of semi-volatiles and facilitate extraction.	●	●	○	—	Expensive relative to other technologies at the scale required.
Ex Situ Biological Treatment (assuming excavation)						
Biopiles	Excavated soils are mixed with soil amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps.	○	○	●	—	Not effective for chlorinated SVOCs. Requires excavation, which is very expensive due to the large volumes of fill and waste.
Composting	Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, hay, manure, and vegetative (e.g., potato) wastes. Proper amendment selection ensure adequate porosity and provides a balance of carbon and nitrogen to promote thermophilic, microbial activity.	○	○	●	—	Not effective for chlorinated SVOCs. Requires excavation, which is very expensive due to the large volumes of fill and waste.
Landfarming	Contaminated soil, sediment, or sludge is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.	◉	○	●	—	Requires excavation, which is very expensive due to the large volumes of fill and waste.
Slurry Phase Biological Treatment	An aqueous slurry is created by combining soil, sediment, or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. Upon completion of the process, the slurry is dewatered and the treated soil is disposed of.	○	○	○	—	Not effective for chlorinated SVOCs. Requires excavation and extensive processing and separation, which are very expensive due to the large volumes of fill and waste.
Ex Situ Physical/Chemical Treatment (assuming excavation)						
Chemical Extraction	Waste contaminated soil and extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.	◉	○	○	—	Requires excavation, extensive processing / separation, and purchase of extractant, all of which are very expensive due to the large volumes of fill and waste.
Chemical Reduction /Oxidation	Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	◉	○	○	—	Requires excavation, extensive processing / separation, and purchase of oxidant, all of which are very expensive due to the large volumes of fill and waste.

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Technology	Description	Effectiveness	Implementability	Relative Cost	Retained?	Comments
Dehalogenation	Reagents are added to soils contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.	○	○	○	—	Requires excavation, extensive processing / separation, and purchase of reagents, all of which are very expensive due to the large volumes of fill and waste.
Separation	Separation techniques concentrate contaminated solids through physical and chemical means. These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).	○	○	○	—	Not effective for NAPL and some COCs. Requires excavation and extensive processing / separation, which are very expensive due to the large volumes of fill and waste.
Soil Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.	◎	○	○	—	Requires excavation, extensive processing / separation, and purchase of leaching agents or surfactants, all of which are very expensive due to the large volumes of fill and waste.
Solidification/Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	◎	○	○	—	Requires excavation, extensive processing / separation, and purchase of stabilizing agent, all of which are very expensive due to the large volumes of fill and waste.
Ex Situ Thermal Treatment (assuming excavation)						
Hot Gas Decontamination	The process involves raising the temperature of the contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.	○	○	○	—	Requires excavation, extensive processing / separation, and thermal treatment, all of which are very expensive due to the large volumes of fill and waste.
Incineration	High temperatures, 870-1,200 °C (1,600- 2,200 °F), are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.	●	○	○	—	Requires excavation, extensive processing / separation, and thermal treatment, all of which are very expensive due to the large volumes of fill and waste.
Open Burn/Open Detonation	In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonatable wave. In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is generally initiated by the detonation of an energetic charge.	○	○	○	—	Not applicable to site conditions.
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.	◎	○	○	—	Requires excavation, extensive processing / separation, and thermal treatment, all of which are very expensive due to the large volumes of fill and waste.
Thermal Desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.	●	○	○	—	Requires excavation, extensive processing / separation, and thermal treatment, all of which are very expensive due to the large volumes of fill and waste.

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Containment						
Landfill Cap	Landfill caps are used for contaminant source control.	●	●	◎	Yes	Effective for all COCs. Relatively moderate cost. Readily implemented.
Landfill Cap Enhancements/Alternatives	The purpose of landfill cover enhancement is to reduce or eliminate contaminant migration (e.g. percolation). Water harvesting and vegetative cover are two ways for landfill cover enhancements. Water harvesting uses runoff enhancement to manage landfill site water balance. Vegetative cover reduces soil moisture via plant uptake and evapotranspiration.	●	●	◎	Yes	Effective for all COCs. Relatively moderate cost. Readily implemented.
Other Treatment						
Excavation, Retrieval, Off-Site Disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.	●	◎	○	—	Requires excavation, extensive processing / separation, transportation, and off-site disposal, all of which are very expensive due to the large volumes of fill and waste.

Symbol key:

● = Higher than average effectiveness and implementability, lower than average cost.

◎ = Average effectiveness and implementability, average cost.

○ = Lower than average effectiveness and implementability, higher than average cost.

Notes:
COC = Chemical of concern. DNAPL = Dense non-aqueous phase liquid. GW = Groundwater. LNAPL = Light non-aqueous phase liquid. VOC = Volatile organic compound.